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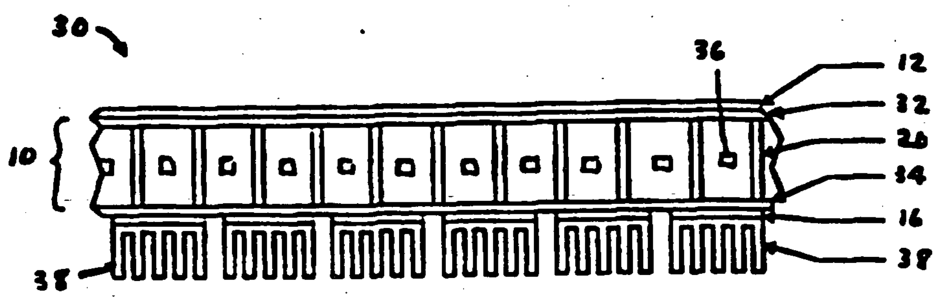

A chuck (10) for holding a substrate (12) for photolithographic processing is described. The chuck has a front surface to which the substrate adheres, the front surface having a plurality of suction apertures for securing the substrate thereto. The rear surface of the chuck has a plurality of temperature control devices (16) spaced uniformly thereon for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface. A method for providing control of the scale of the substrate is also described.

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MAGNIFICATION CONTROL AND THERMAL SUBSTRATE CHUCK FOR PHOTOLITHOGRAPHY

BACKGROUND OF THE INVENTION

The invention relates generally to the field of photolithography. More specifically, the invention provides a method and apparatus for compensating for dimensional errors between a reticle image and an image on a substrate over which the reticle image is intended to be overlaid. The present invention is useful for increasing the overlay accuracy of photolithographic processes, especially those employed in the processing of multi-chip modules (MCMs), semiconductors and flat panel displays. The invention is particularly useful where large individual die or panel images are involved. Still more specifically, the invention provides an overlay error correction method and apparatus whereby a substrate chuck is thermally controlled to provide both isotropic and anisotropic magnification of an image on a substrate attached thereto.

The use of very large glass, silicon, plastic, and ceramic substrates, as well as large images in the flat panel display (FPD) and multi-chip module (MCM) industries have accentuated the overlay mismatch problem. There are several potential sources of overlay mismatch, i.e, scaling mismatch between a reticle pattern and an image or images on a substrate. For example, the generation of the initial substrate image using a step-and-repeat photolithographic process may result in an incorrectly scaled image in cases where the stage scaling is in error. Additionally, substrate exposure to film stress or extreme environments such as those encountered in annealing or deposition processes may cause distortion of the substrate. Incorrect scaling of the reticle or photomask is also a major source of this type of overlay mismatch.

There are several existing techniques for compensating for overlay mismatch. One technique involves

centering the photomask image on the substrate image such that the average error vector is zero. The obvious drawback of such a technique is that the local error vectors increase with distance from the center of the images, resulting in dramatic errors at the periphery of the substrate. Another technique is employed for sub-field step-and-repeat processes. According to this technique, the over all photomask image to substrate image scale mismatch can be averaged over each sub-field exposed. Unfortunately, this technique can suffer from two drawbacks. That is, the error vectors would tend to increase at the periphery of each sub-region, and an increase in the number of sub-regions per substrate would tend to decrease throughput and introduce stitching errors. Finally, some techniques attempt to compensate for overlay mismatch by adjusting the magnification of the lens system used to project the photomask image onto the substrate. For large area substrates this technique suffers from obvious drawbacks, including the cost and complexity of such a magnification system.

From the foregoing, it is evident that improvements are needed in techniques for compensating for overlay mismatch in photolithographic processes.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus which does not suffer from the drawbacks of the techniques described above and which compensates for overlay mismatch with a high degree of accuracy and reliability. The invention provides a substrate chuck which may be precisely thermally controlled to provide magnification of a substrate attached thereto, thereby providing magnification of any image on the substrate. The thermal chuck of the present invention performs several functions. It holds the substrate in a substantially fixed position, flattens the substrate against its front surface, and, as described above, controls the temperature and therefore the size or scale of the substrate. The thermal control of the chuck and substrate allows for scale adjustments in processes which depend on a specific

repeatable registration tolerance. The present invention is particularly useful in lithography processes which employ, for example, unity magnification lens systems, proximity printing, or contact printing. In general, the lithography tools employed in such processes do not have the capability of changing image magnification to compensate for substrate expansion or compaction resulting from thermal or thin film processes. The thermal chuck of the present invention is easily incorporated into such lithography tools to provide magnification control thereby eliminating this shortcoming.

Various embodiments of the present invention may be constructed with structural architectures that are stiff, low mass, and symmetric, with materials with appropriate thermal expansion properties and high thermal agility. This allows the chuck to change temperature quickly yet retain its flat surface. Some embodiments incorporate an array of thermal devices to heat and cool it. Also included in such embodiments are means for the array of thermal devices to dissipate their waste heat. This allows the chuck to change temperature and minimize its effect on its surroundings. A substrate image to photomask image alignment process is also described herein which measures the scale difference between at least two points. In order to overlay the exposure of a subsequent image from a photomask onto a previous image on a substrate the two images must first be aligned. This may be done using non-actinic wavelength light (i.e., green) which will not expose the substrate photoresist. By aligning three or more points on the photomask to the corresponding points on the substrate, information regarding rotational alignment of the photomask and substrate as well as a comparison of scale between the photomask and substrate may be obtained. If the scaling error is assumed to be isotropic, this same alignment can be performed using only two points. This allows for the calculation of the temperature change in the chuck and substrate required to change the scale of the substrate to match the image size of the photomask. The greatest sensitivity in this determination is achieved when the two

points are separated by the greatest distance over the extent of the substrate and mask.

According to the invention, a chuck for holding a substrate is described. The chuck has a front surface which includes means for securing the substrate thereto. Coupled to the front surface of the chuck are means for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered thereto. According one embodiment, the manipulating means are operable to independently control a plurality of regions within the temperature distribution of the front surface. In a more specific embodiment, a chuck for holding a substrate for photolithographic processing is described. According to one embodiment, the front surface of the chuck has a plurality of suction apertures for securing the substrate thereto. The rear surface of the chuck has a plurality of temperature control devices spaced uniformly thereon for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface.

A method for providing control of the scale of a substrate is also described. The substrate is adhered to a front surface of a chuck and the temperature distribution of the front surface of the chuck is manipulated, thereby adjusting the scale of the substrate. A more specific method relating to a photolithographic process is also described in which a plurality of levels of adherence are provided between the substrate and the front surface of the chuck. A reduced level of adherence (e.g., a soft vacuum) is provided to allow the substrate and chuck to change size with respect to each other without distorting or breaking the substrate. The temperature distribution of the front surface of the chuck is manipulated, thereby adjusting the scale of the substrate to a first scale which is determined with reference to a second image on an associated reticle. The reduced level of adherence between the substrate and the front surface of the chuck is employed to relieve stress on the substrate due to the scale changes which result from the manipulating step.

A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a front view of a specific embodiment of the invention illustrating the placement of a substrate;

Fig. 2 is a rear view of a specific embodiment of the invention illustrating an array of solid state heat pumps attached thereto;

Fig. 3 is a cross-sectional view of a specific embodiment of the present invention parallel to its front surface illustrating one type of stiffening structure;

Fig. 4 is a cross-sectional side view of a specific embodiment of the invention; and

Fig. 5 is cross-sectional side view of another specific embodiment of the invention; and

Fig. 6 is cross-sectional side view of still another embodiment of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Fig. 1 is a front view of a specific embodiment of a chuck 10 designed according to the present invention. A substrate 12 is shown mounted on the front surface of chuck 10. As can be seen, chuck 10 is substantially thicker than substrate 12 so that substrate 12 will conform to the flatness of the front surface of chuck 10. Three alignment pins 14 provide nominal alignment of substrate 12 to the lithography tool employing chuck 10. The front surface of chuck 10 includes a pattern of holes (not shown) which provide vacuum suction which in turn provides adherence between substrate 12 and chuck 10. The vacuum suction is of sufficient force to cause the substrate to conform to the chuck surface within a tolerance defined by the depth of focus of the optical system. In specific embodiments of the invention, the chuck is larger in its surface dimensions than the substrates with which it is used to ensure that the entire surface of each substrate is in

contact with the chuck. This, in turn, ensures control of the entire substrate.

Fig. 2 is a rear view of chuck 10 of Fig. 1. An array of heat pumps 16 are arranged on the rear surface of chuck 10 in a uniform pattern. Heat pumps 16, which are shown without any heat sinking structures, are adhered to the rear surface of chuck 10 with good thermal contact. In a specific embodiment, heat pumps 16 comprise Peltier thermoelectric heat pumps. As shown in Fig. 2, many relatively small heat pumps are employed to manipulate the temperature of the chuck because, in general, heat pumps 16 and chuck 10 are likely to be made of a different materials having different thermal expansion coefficients. If one large heat pump were used, the differential expansion between the heat pump and the chuck would warp the chuck and therefore the substrate and its image.

Fig. 3 is a cross-sectional view of chuck 10 parallel to its front surface. This view shows substantial side walls 18 providing support for the structure of the chuck. Such side walls are required for most embodiments of the invention employing vacuum suction on the front surface. Also shown in Fig. 3 is an inner stiffening structure 20 comprising a hexagonal “honey comb” pattern of structural webs. As can be seen, stiffening structure 20 forms a plurality of prismatic cells each having a hexagonal cross-section. The longitudinal axes of the cells are substantially perpendicular to the front and rear surfaces of the chuck. It will be understood that there are many other configurations which may be employed to perform the function of stiffening structure 20. For example, periodic structures having a variety of polygonal cross-sections may be substituted for the structure shown.

Stiffening structure 20 provides the chuck with superior specific stiffness and low heat capacity. Stiffening structure 20 also provides a thermal heat path from the rear surface of the chuck which is populated with heat pumps 16 (Fig. 2) to the front surface where the substrate is mounted. In embodiments of the invention where the interior of the

chuck is evacuated (e.g., for vacuum suction) the walls of stiffening structure 20 have apertures which allow pressure to equalize throughout the interior of the chuck thereby preventing distortion of the chuck which might otherwise result from differential pressures in its interior.

Fig. 4 is a cross-sectional side view of a chuck assembly 30 according to a specific embodiment of the invention. A substrate 12 is secured to the front surface 32 of chuck 10. Heat pumps 16 are secured to the rear surface 34. Front and rear surfaces 32 and 34 and stiffening structure 20 form a substantially symmetric assembly. Apertures 36 in the walls of stiffening structure 20 allow pressure equalization inside chuck 10 as described above. Heat sink fins 38 are secured to each heat pump 16. Air flow is directed through the fin array to dissipate the waste heat.

Fig. 5 is a cross-sectional side view of a chuck assembly 40 according to another embodiment of the invention. The embodiment of Fig. 5 is similar to that of Fig. 4 except that in place of heat sink fans, a large isothermal body 42 is secured to heat pumps 16 which provides a low resistance thermal conduction path for waste heat to a nearly ideal heat sink.

Fig. 6 is a cross-sectional side view of a chuck assembly 50 according to still another embodiment of the invention. The embodiment of Fig. 6 utilizes the stiffness and flatness of isothermal mass 42 as a base structure or platen. The chuck therefore does not require the stiffening structure architecture of Figs. 4 and 5. Rather, in this embodiment, substrate 12 is secured to a single piece chuck plate 52 with vacuum suction. Chuck plate 52, heat pumps 16, and isothermal platen 42 are all be mutually adhered together to form a good thermal bond. Heat pumps 16 may be permanently adhered to either chuck plate 52 or isothermal base 42, either separately or as, for example, a Peltier assembly. In any case, the heat pumps are the same thickness to avoid distortion of chuck plate 52. In a specific embodiment, the array of heat pumps 16 are potted together into an assembly and lapped flat.

According to another embodiment, chuck plate 52, heat pumps 16, and isothermal base 42 are coupled together using vacuum suction. The advantage of such an impermanent bond is that stress due to the differential expansion of these chuck assembly elements may be relieved at will. A seal 54 surrounds the perimeter of the array of heat pumps 16 to contain the vacuum, holding all the chuck assembly elements together in good thermal contact, and keeping them flat against isothermal base 42.

To properly function as a substrate chuck, the chuck of the present invention must be stiff and flat, and have means for securing the substrate to the chuck, such as, for example, with vacuum suction as is common in the industry. The chuck may be made from a material with nearly the same thermal expansion coefficient as the substrate material thereby minimizing the chances of inducing stress in the substrate while manipulating the temperature of the chuck. Alternatively, the chuck may be made from a material with a zero thermal expansion coefficient thereby minimizing induced stress that may result in warpage of the chuck while manipulating its temperature.

Low heat capacity and high thermal conductivity of the chuck are also very important. Low heat capacity is important to reducing the amount of energy required to change the temperature of the chuck by a given amount. Low heat capacity is achieved by choosing a material with a low specific heat, and by constructing the chuck with a minimum mass while maintaining the necessary stiffness. One way in which this can be accomplished is by designing the chuck with a hollow core with a stiffening structure and solid outer skins as described with reference to Figs. 4 and 5.

High thermal conductivity is important to maintaining a uniform temperature distribution on the surface of the chuck. A non-uniform temperature distribution over a substrate causes non-uniform magnification and mechanical stress in the substrate. Similarly, undesired temperature gradients in the chuck may cause warpage of the chuck itself which would, in turn, induce magnification and focus errors.

Temperature gradients can also result in localized distortions which can cause localized phenomena such as focus shifts, differential magnification, displacements and rotations which would appear as localized and inconsistent overlay errors. High thermal conductivity of the chuck material also allows both the chuck and the substrate to settle to a uniform temperature quickly.

The thermal chuck of the present invention may also be employed to control the dimensional scale of a substrate in an anisotropic way. For example, if a substrate demonstrates one scaling error in one dimension (e.g., length) and a different scaling error in another dimension (e.g., width), the thermal chuck of the present invention may be used to compensate for these different scaling errors simultaneously by creating one thermal gradient across its length and another across its width. This may be accomplished, for example, using the array of heat pumps 16 shown in Figs. 2 and 4-6. By individually controlling these heat pumps, individual regions within the temperature distribution of the front surface of the chuck may be manipulated, thus allowing many different temperature distributions to be generated. The greater the number of heat pumps and/or the thinner the front surface, the more smoothly the temperature distribution may be controlled.

The present invention may also be employed with other techniques to achieve anisotropic scaling. For example, according to one technique, the thermal chuck is first controlled to provide isotropic manipulation of the substrate thereby compensating for the average scaling error over the substrate. Then, simultaneous with the scan, the relative position of the reticle is smoothly and continuously adjusted with respect to the substrate in the same direction as the scan using an alignment mechanism. According to a more specific embodiment, the thermal chuck is employed to compensate for the average (isotropic) error and some slowly varying anisotropic errors. The smooth and continuous relative motion of the reticle with respect to the substrate is then used to perform fine adjustments which compensate for localized anisotropic errors in the scan axis.

In embodiments where the chuck is constructed of a material having a non-zero thermal expansion coefficient, kinematic support of the chuck is necessary because the chuck changes size relative to is support structure. An over-constrained support structure induces stress in the chuck as its temperature changes resulting in undesirable warping. In embodiments where the chuck is constructed of a material having a zero thermal expansion coefficient, the chuck may be mounted rigidly to a stable structure.

The temperature control system of the invention must be capable of both heating and cooling the chuck and substrate to allow for either polarity of magnification. It must also be capable of heating and cooling quickly. Heating quickly and with uniformity is relatively easy with ohmic heaters. However, cooling is much more difficult. Circulation of chilled water is an option, but this technique is relatively slow due to the thermal mass of the water and the circulation time. Peltier thermoelectric heat pump devices are an excellent option which provide temperature agility, high heat rates, and good uniformity where many devices are spaced evenly over the surface of the chuck. With Peltier devices the waste heat from the heat transfer operation is removed from the back side of the Peltier devices. For removal of this waste heat, water circulation may be employed since high heat capacity is desirable and response time is not critical.

Because they are likely to have a different thermal expansion coefficient than the chuck, the individual Peltier devices should be relatively small in area so that the stresses in the chuck which are induced as it changes temperature are minimized. Differential stress can be minimized further by securing the Peltier devices to the chuck with a high thermal conductivity adhesive which also has a relatively low modulus of elasticity.

An alternative method for removing waste heat from the Peltier devices is the use of forced air over or through heat sink fins on the backs of the Peltier devices. Another method for removing waste heat from the Peltier devices may be used only with embodiments where the chuck is constructed of a

zero thermal expansion coefficient material, or where a stress relieving technique is employed which removes induced stresses from the chuck assembly and/or substrate. This technique involves sandwiching the Peltier devices between the chuck and a flat, massive, constant temperature structure having a high thermal conductivity.

In specific embodiments, temperature sensors such as, for example, thermocouples or thermistors, are attached to the chuck to monitor and facilitate the control of its temperature distribution. Such sensors are particularly useful for embodiments of the invention which exercise anisotropic control of the chuck's temperature distribution.

A measure of the suitability of a given material for use with the present invention, i.e., a "goodness factor", can be determined with reference to various of the characteristics discussed above. Such a goodness factor, G, is given by the relationship:

$$G = \frac{\text{(specific stiffness)} \times \text{(thermal conductivity)}}{\text{(specific heat)}}. \qquad (1)$$

A comparison of many common engineering materials has shown graphite and beryllium oxide (BeO) as particularly "good" materials from which to construct the chuck. The outer skins (i.e., front and rear surfaces) of the chuck are preferably at least as thick as the substrate to facilitate the effective distribution of heat, as well as to provide sufficient stiffness relative to the stiffness of the substrate. According to specific embodiments, the inner stiffening structure is constructed of the same material as the outer skins to maintain dimensional stability. However, in some embodiments, the stiffening structure may also be plated with a material having a high thermal conductivity and a low elastic modulus such as, for example, copper (Cu) or aluminum (Al), to increase thermal conductivity between the front and rear surfaces of the chuck. When employing such a stiffening structure it is important to maintain the symmetry of the chuck assembly structure.

According to a specific embodiment of the invention, a substrate is loaded onto the chuck (of Figs. 1-3) and a soft vacuum is applied to secure the substrate sufficiently to establish good thermal contact with the chuck surface, but also allow for differential expansion between the substrate and the chuck. The scale of the image on the substrate is measured to determine the scale adjustment required to match the scale of the photomask image. More specifically, the rotational misalignment and the isotropic magnification error are determined as follows. Initially, a simple alignment between the substrate and the reticle is achieved by measuring the alignment errors $(\Delta x_1, \Delta y_1)$ between a point (x_1, y_1) on the substrate and its corresponding point on the reticle, and then adjusting the x,y position of either the substrate or the reticle to reduce the error to zero. Once this simple alignment is achieved, alignment data $(\Delta x_2, \Delta y_2)$ is acquired for a second point (x_2, y_2) on the substrate and its corresponding point on the reticle. The rotational misalignment between the reticle and the substrate is given by

$$[\Delta x_2/(y_2-y_1) + \Delta y_2/(x_2-x_1)]/2 \tag{2}$$

and the isotropic or average magnification error is given by

$$[\Delta y_2/(y_2-y_1) + \Delta x_2/(x_2-x_1)]/2 \tag{3}$$

According to another embodiment, a fairly rigorous alignment between the substrate and the reticle is conducted (especially where the expansion behavior of the substrate is not known) by measuring the alignment errors $(\Delta x_i, \Delta y_i)$ between a point on the substrate and its corresponding point on the reticle, and then repeating the process for at least two more points on the substrate. Once the data have been collected, they may be analyzed using the following expressions:

$$\delta x = \alpha x + (\Delta M/M)x_0 - \theta y_0 + \epsilon \tag{4}$$

$$\delta y = \alpha y + (\Delta M/M)y_0 - \theta x_0 - \epsilon \tag{5}$$

where the constants αx and αy correspond to an origin shift. The terms which are linear in field placement are due to magnification errors ($\Delta M/M$) and reticle rotation errors. Once the normal equations are solved, the temperature change needed to compensate for scaling errors may be applied. Appropriate rotational adjustment may also be applied to compensate for rotation errors. Repeating the alignment process may be required to confirm or refine the result. For subsequent repetitions of the alignment process, fewer alignment points may be employed to reduce overall alignment time. The number of alignment points may also be reduced for subsequent substrates as the behavior of the substrate scaling becomes known. However, the number of alignment points on any given substrate may not be reduced below two if proper rotational alignment is to be achieved.

For cases of anisotropic expansion, more than two alignment points are required to determine the scale error as a function of position on the substrate. For constant but different scales in two dimensions, three non-collinear alignment points are required to determine the scale in the two dimensions in addition to overlay in two translational and one rotational axes. If there are linear scale gradients in two dimensions, five alignments points are required. When higher order scale errors occur, some pattern or degree of predictability may also occur. If the coefficients of the higher order terms can be correlated to the first order scale, a determination of the first order scale using only two alignment points may suffice.

The temperature of the substrate and chuck is also measured. The temperature of the substrate and chuck which would provide the necessary expansion or contraction of the substrate to minimize the scale error is then calculated. The temperature of the substrate and chuck is then servoed to the desired value by heating or cooling the chuck mass as required. After thermal equilibrium of the substrate and chuck assembly is achieved, a stronger vacuum is applied to more firmly secure the substrate to the chuck for the photolithographic process.

For the embodiment of the invention which employs an isothermal platen without permanently adhered components (e.g., the chuck assembly described above with reference to Fig. 6), the vacuum that holds the chuck and the heat pumps to the isothermal platen may be relaxed momentarily after thermal equilibrium is achieved to allow any stress resulting from differential expansion to be released.

To further augment the reduction of overlay errors using the thermal chuck of the present invention, instead of aligning the photomask image only once to the entire substrate image, a specific embodiment of the invention aligns each individual panel (or potentially many isolated areas) on a substrate to the corresponding photomask area before exposure of that particular area, repeating the process for each area on the substrate. This technique is particularly useful where there are multiple panels (e.g., product images) on a single substrate.

Various embodiments of the invention may be useful in, for example, the manufacture of flat panel displays (FPDs). Thermal, thin-film and compaction effects in FPD processes have been or can be characterized. To a significant extent, therefore, the effective magnification change of the substrate for each step of such a process may be predicted. Using this information, the present invention may be operated in a so-called static mode in which a single constant chuck temperature is employed for each process step, i.e., the scale of the substrate may be manipulated for each process step to compensate for the magnification change corresponding to the particular process step. In a more specific embodiment, differently scaled reticles could be produced for selected process steps thereby reducing the required dynamic range of the thermal chuck. That is, part of the compensation for overlay mismatch may be achieved by the use of differently scaled reticles and part may be achieved using the properties of the thermal chuck as described above.

It should also be noted that, because a substrate chuck represents a relatively costly system element when compared to the cost of a single substrate, it is important

that the front surface of a substrate chuck be harder than the substrates it is designed to handle so that the substrates do not abrade the surface of the chuck.

The above description is illustrative and not restrictive. Many variations of the invention will become apparent to those skilled in the art upon review of this disclosure. For example, different materials of construction may be used if chosen carefully. The invention can be mounted in various orientations, and with a variety of mounting techniques. It can incorporate various sensors to facilitate operation. Holes or other means may be added to the chuck surface or structure to facilitate substrate exchange. Different operating sequences can be used to tailor operation to a particular application. To decrease the time required for a substrate to get to a new equilibrium temperature on the thermal chuck, the substrates in a cassette could be preheated with heated air to a temperature near the average temperature of the thermal chuck. This invention may also be incorporated into many different types of equipment. The scope of the invention should therefore be determined not just with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

WHAT IS CLAIMED IS:

1. A chuck assembly for holding a substrate, comprising:

a front surface to which the substrate adheres, the front surface having means for securing the substrate to the front surface, the front surface being characterized by a temperature distribution; and

coupled to the front surface, a plurality of temperature control devices for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface.

2. The chuck assembly of claim 1 wherein the means for securing the substrate to the front surface comprise a plurality of suction apertures in the front surface.

3. The chuck assembly of claim 1 wherein the means for securing the substrate to the front surface are operable to provide a plurality of levels of adherence between the substrate and the front surface.

4. The chuck assembly of claim 1 wherein the plurality of temperature control devices is operable to create an anisotropic temperature distribution across the front surface of the chuck assembly.

5. The chuck assembly of claim 1 further comprising a rear surface coupled to and opposite the front surface, the plurality of temperature control devices being spaced uniformly on the rear surface.

6. The chuck assembly of claim 1 wherein each of the plurality of temperature control devices comprises a Peltier heat pump.

7. The chuck assembly of claim 1 wherein each of the plurality of temperature control devices is individually controlled.

8. The chuck assembly of claim 1 wherein each of the plurality of temperature control devices has an individual heat sink coupled thereto.

9. The chuck assembly of claim 1 further comprising a rear surface coupled to the front surface via a stiffening structure by which heat may be conducted from the rear surface to the front surface.

10. The chuck assembly of claim 9 wherein the stiffening structure forms a plurality of prismatic cells each having a polygonal cross-section, a longitudinal axis, and walls, the longitudinal axes of the prismatic cells being substantially perpendicular to the front and rear surfaces of the chuck assembly.

11. The chuck assembly of claim 10 wherein each of the prismatic cells has apertures formed in the walls thereof to prevent differential pressures from forming within the chuck assembly.

12. The chuck assembly of claim 1 wherein the front surface of the chuck assembly comprises a material characterized by a zero thermal expansion coefficient.

13. The chuck assembly of claim 1 wherein the front surface of the chuck assembly and the substrate are characterized by thermal expansion coefficients which are substantially the same.

14. A chuck assembly for holding a substrate for photolithographic processing, comprising:

a front surface to which the substrate adheres, the front surface having a plurality of suction apertures for

securing the substrate to the front surface, the front surface being characterized by a temperature distribution; and

a rear surface coupled to and opposite the front surface, the rear surface having a plurality of temperature control devices spaced uniformly thereon for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface.

15. The chuck assembly of claim 14 further comprising a base coupled to the plurality of temperature control devices opposite the rear surface, the base, the plurality of temperature control devices, and the rear surface being held together using vacuum suction.

16. The chuck assembly of claim 14 wherein the plurality of temperature control devices is operable to create an anisotropic temperature distribution across the front surface of the chuck assembly.

17. A method for providing control of the scale of a substrate comprising the steps of:

adhering the substrate to a front surface of a chuck, the front surface being characterized by a temperature distribution; and

controlling a plurality of temperature control devices coupled to the front surface of the chuck, thereby manipulating the temperature distribution of the front surface of the chuck, thereby adjusting the scale of the substrate.

18. The method of claim 17 wherein the adhering step comprises providing a plurality of levels of adherence, differing levels of adherence being employed to compensate for scale changes resulting from the manipulating step.

19. The method of claim 17 wherein the adhering step comprises providing a first level of adherence between the substrate and the front surface of the chuck, the method

further comprising the step of providing a second level of adherence between the substrate and the front surface of the chuck to relieve stress on the substrate resulting from the manipulating step, the second level of adherence being less than the first level of adherence.

20. The method of claim 17 wherein the adhering step comprises providing a first level of adherence between the substrate and the front surface of the chuck, the method further comprising the step of providing a second level of adherence between the substrate and the front surface of the chuck to more securely couple the substrate to the front surface of the chuck, the second level of adherence being greater than the first level of adherence.

21. The method of claim 17 wherein the manipulating step comprises uniformly manipulating the temperature distribution of the front surface of the chuck to effect isotropic control of the scale of the substrate.

22. The method of claim 17 wherein the manipulating step comprises selectively manipulating the temperature distribution of the front surface of the chuck to effect anisotropic control of the scale of the substrate.

23. The method of claim 17 wherein the manipulating step comprises uniformly increasing the temperature of the front surface thereby resulting in controlled expansion of the substrate.

24. The method of claim 17 wherein the manipulating step comprises uniformly decreasing the temperature of the front surface thereby resulting in controlled contraction of the substrate.

25. The method of claim 17 wherein the manipulating step comprises adjusting the scale of the substrate until a first image on the substrate has reached a first scale, the

first scale being determined with reference to a second image on an associated reticle.

26. The method of claim 25 wherein the first image comprises a plurality of portions, the step of adjusting the scale of the substrate being performed for each portion of the first image.

27. The method of claim 17 wherein the manipulating step adjusts the scale of the substrate with reference to a reticle pattern, the method further comprising the step of determining an alignment error by comparing a plurality of alignment points on the substrate to corresponding locations on the reticle pattern, the manipulating step adjusting the scale of the substrate to compensate for the alignment error.

28. The method of claim 27 wherein the substrate is characterized by anisotropic expansion and the plurality of alignment points comprises at least three alignment points which are not collinear.

29. The method of claim 28 wherein the anisotropic expansion is characterized by linear gradients in two dimensions and the at least three alignment points comprise at least five alignment points.

30. The method of claim 17 wherein the chuck is characterized by an average temperature and the steps of adhering and manipulating are performed for a plurality of substrates, the plurality of substrates being stored in a cassette before the adhering and manipulating steps, the method further comprising the step of preheating the plurality of substrates stored in the cassette to the average temperature of the chuck.

31. A method for providing control of the scale of a substrate in a photolithographic process, the method comprising the steps of:

providing a plurality of levels of adherence between the substrate and a front surface of a chuck, the front surface being characterized by a temperature distribution; and

manipulating the temperature distribution of the front surface of the chuck, thereby adjusting the scale of the substrate to a first scale, the first scale being determined with reference to a second image on an associated reticle;

wherein differing levels of adherence are employed to compensate for scale changes resulting from the manipulating step.

32. A method for providing control of the scale of a substrate in a photolithographic process, the photolithographic process having a plurality of process steps, each process step being characterized by a magnification change of the substrate, the method comprising the steps of:

adhering the substrate to a front surface of a chuck, the front surface being characterized by a temperature distribution; and

manipulating the temperature distribution of the front surface of the chuck for each process step, thereby adjusting the scale of the substrate to compensate for the corresponding magnification change.

33. The method of claim 32 wherein the front surface of the chuck is characterized by a dynamic range, the method further comprising the step of providing differently scaled reticles for at least one process step thereby partially compensating for the corresponding magnification change.

34. A method for compensating for scaling errors in a photolithographic process wherein a reticle has relative position with respect to a substrate, the method comprising the steps of:

adhering the substrate to a front surface of a chuck, the front surface being characterized by a temperature distribution;

manipulating the temperature distribution of the front surface of the chuck, thereby adjusting the scale of the substrate;

performing a photolithographic scan of the substrate; and

simultaneous with the photolithographic scan, adjusting the relative position of the reticle with respect to the substrate in a substantially continuous manner thereby compensating for localized anisotropic scaling errors.

35. The method of claim 34 wherein the temperature distribution of the front surface of the chuck is manipulated to compensate for isotropic scaling errors.

36. The method of claim 35 wherein the temperature distribution of the front surface of the chuck is also manipulated to compensate for slowly varying anisotropic errors.

37. A method for compensating for scaling errors in a photolithographic process wherein a reticle has relative position with respect to a substrate, the method comprising the steps of:

performing a photolithographic scan of the substrate; and

simultaneous with the photolithographic scan, adjusting the relative position of the reticle with respect to the substrate in a substantially continuous manner thereby compensating for localized anisotropic scaling errors.

38. A chuck assembly for holding a substrate, comprising:

a front surface to which the substrate adheres, the front surface having means for securing the substrate to the front surface, the front surface being characterized by a temperature distribution; and

coupled to the front surface, means for manipulating the temperature distribution of the front surface, thereby

allowing controlled expansion and contraction of the substrate adhered to the front surface, the manipulating means being operable to independently control a plurality of regions within the temperature distribution.

FIG. 1

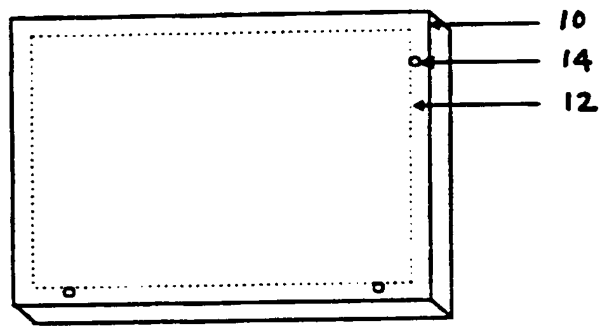


FIG. 2

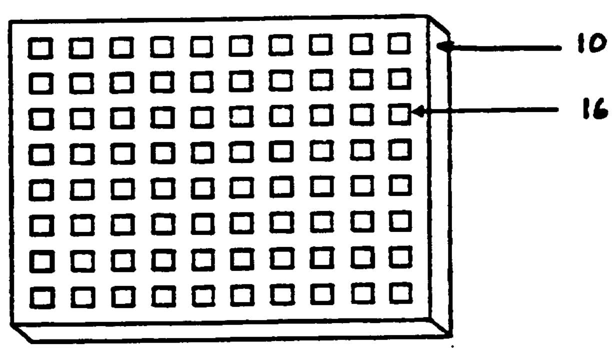


FIG. 3

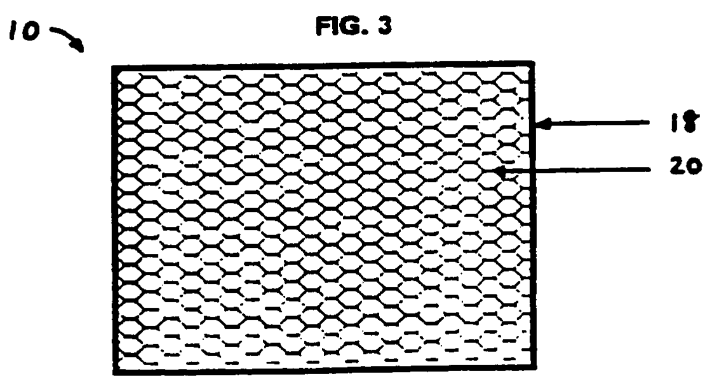


FIG. 4

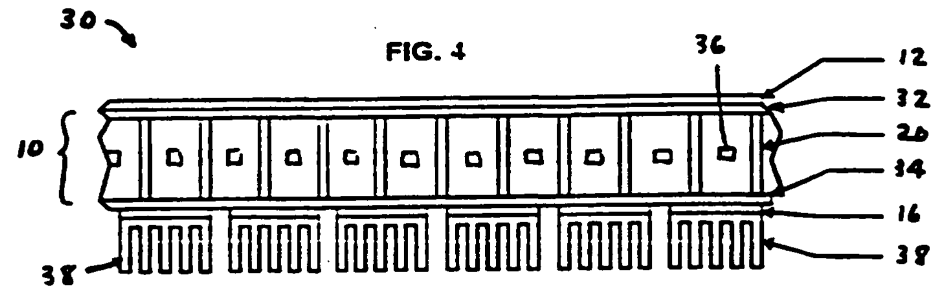


FIG. 5

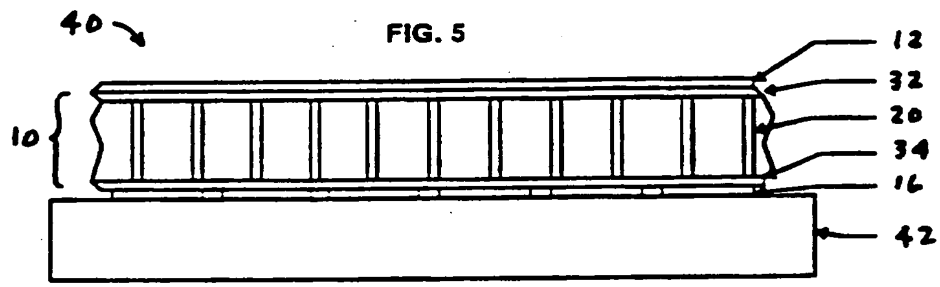
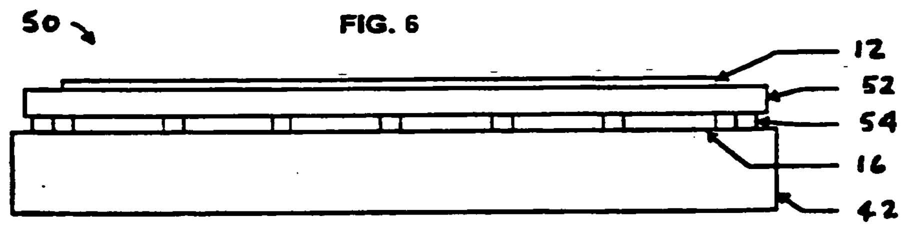


FIG. 6



INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
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B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)

U.S. : 355/30, 53, 55, 72, 73, 91; 219/243, 385, 405, 411, 526; 118/50.1, 728

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, JAPIO, WPIDS
search terms: wafer, semiconductor, substrate, chuck, temperature, vacuum

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,134,436A (Fujioka) 28 JULY 1992 col. 4, lines 1-6, 48-64 col. 6, lines 49-68 Figs. 2B, 6	1, 4-8, 14, 16, 17, 21-24, 38
Y	US 4,564,284A (Tsutsui) 14 JANUARY 1986 col. 3, lines 6-46, 68-69 col. 4, lines 1-20	12, 13
Y	US 5,155,652A (Logan et al.) 13 OCTOBER 1992 Fig. 1 col. 3, lines 54-68 col. 4, lines 1-13	9-11
A	US 4,503,335A (Takahashi) 05 MARCH 1985	1-16, 38

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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INTERNATIONAL SEARCH REPORT

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PCT/US96/16272

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,270,771A (Sato) 14 DECEMBER 1993 Figs. 2-4 col. 2, lines 40-50	27-28
Y	US 5,563,683A (Kamiya) 08 OCTOBER 1996 col. 2, lines 39-65 Figs. 4, 5A-B	2-3, 15

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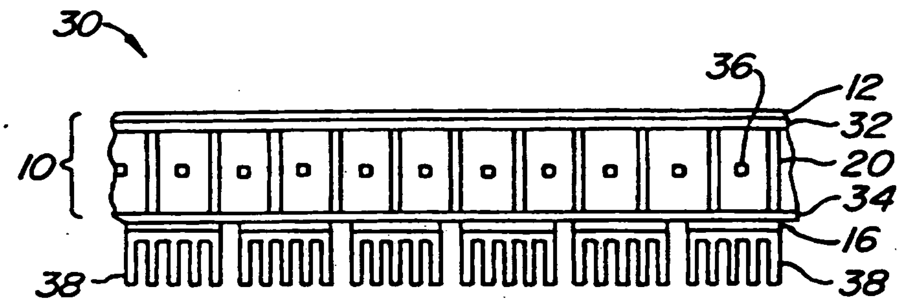
(54) Title: MAGNIFICATION CONTROL AND THERMAL SUBSTRATE CHUCK FOR PHOTOLITHOGRAPHY

(57) Abstract



A chuck (10) for holding a substrate (12) for photolithographic processing is described. The chuck has a front surface to which the substrate adheres, the front surface having a plurality of suction apertures for securing the substrate thereto. The rear surface of the chuck has a plurality of temperature control devices (16) spaced uniformly thereon for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface. A method for providing control of the scale of the substrate is also described.

* (Referred to in PCT Gazette No. 42/1997, Section II)

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MAGNIFICATION CONTROL AND THERMAL SUBSTRATE CHUCK FOR PHOTOLITHOGRAPHY

BACKGROUND OF THE INVENTION

The invention relates generally to the field of photolithography. More specifically, the invention provides a method and apparatus for compensating for dimensional errors between a reticle image and an image on a substrate over which the reticle image is intended to be overlaid. The present invention is useful for increasing the overlay accuracy of photolithographic processes, especially those employed in the processing of multi-chip modules (MCMs), semiconductors and flat panel displays. The invention is particularly useful where large individual die or panel images are involved. Still more specifically, the invention provides an overlay error correction method and apparatus whereby a substrate chuck is thermally controlled to provide both isotropic and anisotropic magnification of an image on a substrate attached thereto.

The use of very large glass, silicon, plastic, and ceramic substrates, as well as large images in the flat panel display (FPD) and multi-chip module (MCM) industries have accentuated the overlay mismatch problem. There are several potential sources of overlay mismatch, i.e, scaling mismatch between a reticle pattern and an image or images on a substrate. For example, the generation of the initial substrate image using a step-and-repeat photolithographic process may result in an incorrectly scaled image in cases where the stage scaling is in error. Additionally, substrate exposure to film stress or extreme environments such as those encountered in annealing or deposition processes may cause distortion of the substrate. Incorrect scaling of the reticle or photomask is also a major source of this type of overlay mismatch.

There are several existing techniques for compensating for overlay mismatch. One technique involves

centering the photomask image on the substrate image such that the average error vector is zero. The obvious drawback of such a technique is that the local error vectors increase with distance from the center of the images, resulting in dramatic errors at the periphery of the substrate. Another technique is employed for sub-field step-and-repeat processes. According to this technique, the over all photomask image to substrate image scale mismatch can be averaged over each sub-field exposed. Unfortunately, this technique can suffer from two drawbacks. That is, the error vectors would tend to increase at the periphery of each sub-region, and an increase in the number of sub-regions per substrate would tend to decrease throughput and introduce stitching errors. Finally, some techniques attempt to compensate for overlay mismatch by adjusting the magnification of the lens system used to project the photomask image onto the substrate. For large area substrates this technique suffers from obvious drawbacks, including the cost and complexity of such a magnification system.

From the foregoing, it is evident that improvements are needed in techniques for compensating for overlay mismatch in photolithographic processes.

SUMMARY OF THE INVENTION

The present invention provides a method and apparatus which does not suffer from the drawbacks of the techniques described above and which compensates for overlay mismatch with a high degree of accuracy and reliability. The invention provides a substrate chuck which may be precisely thermally controlled to provide magnification of a substrate attached thereto, thereby providing magnification of any image on the substrate. The thermal chuck of the present invention performs several functions. It holds the substrate in a substantially fixed position, flattens the substrate against its front surface, and, as described above, controls the temperature and therefore the size or scale of the substrate. The thermal control of the chuck and substrate allows for scale adjustments in processes which depend on a specific

repeatable registration tolerance. The present invention is particularly useful in lithography processes which employ, for example, unity magnification lens systems, proximity printing, or contact printing. In general, the lithography tools employed in such processes do not have the capability of changing image magnification to compensate for substrate expansion or compaction resulting from thermal or thin film processes. The thermal chuck of the present invention is easily incorporated into such lithography tools to provide magnification control thereby eliminating this shortcoming.

Various embodiments of the present invention may be constructed with structural architectures that are stiff, low mass, and symmetric, with materials with appropriate thermal expansion properties and high thermal agility. This allows the chuck to change temperature quickly yet retain its flat surface. Some embodiments incorporate an array of thermal devices to heat and cool it. Also included in such embodiments are means for the array of thermal devices to dissipate their waste heat. This allows the chuck to change temperature and minimize its effect on its surroundings. A substrate image to photomask image alignment process is also described herein which measures the scale difference between at least two points. In order to overlay the exposure of a subsequent image from a photomask onto a previous image on a substrate the two images must first be aligned. This may be done using non-actinic wavelength light (i.e., green) which will not expose the substrate photoresist. By aligning three or more points on the photomask to the corresponding points on the substrate, information regarding rotational alignment of the photomask and substrate as well as a comparison of scale between the photomask and substrate may be obtained. If the scaling error is assumed to be isotropic, this same alignment can be performed using only two points. This allows for the calculation of the temperature change in the chuck and substrate required to change the scale of the substrate to match the image size of the photomask. The greatest sensitivity in this determination is achieved when the two

points are separated by the greatest distance over the extent of the substrate and mask.

According to the invention, a chuck for holding a substrate is described. The chuck has a front surface which includes means for securing the substrate thereto. Coupled to the front surface of the chuck are means for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered thereto. According one embodiment, the manipulating means are operable to independently control a plurality of regions within the temperature distribution of the front surface. In a more specific embodiment, a chuck for holding a substrate for photolithographic processing is described. According to one embodiment, the front surface of the chuck has a plurality of suction apertures for securing the substrate thereto. The rear surface of the chuck has a plurality of temperature control devices spaced uniformly thereon for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface.

A method for providing control of the scale of a substrate is also described. The substrate is adhered to a front surface of a chuck and the temperature distribution of the front surface of the chuck is manipulated, thereby adjusting the scale of the substrate. A more specific method relating to a photolithographic process is also described in which a plurality of levels of adherence are provided between the substrate and the front surface of the chuck. A reduced level of adherence (e.g., a soft vacuum) is provided to allow the substrate and chuck to change size with respect to each other without distorting or breaking the substrate. The temperature distribution of the front surface of the chuck is manipulated, thereby adjusting the scale of the substrate to a first scale which is determined with reference to a second image on an associated reticle. The reduced level of adherence between the substrate and the front surface of the chuck is employed to relieve stress on the substrate due to the scale changes which result from the manipulating step.

A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a front view of a specific embodiment of the invention illustrating the placement of a substrate;

Fig. 2 is a rear view of a specific embodiment of the invention illustrating an array of solid state heat pumps attached thereto;

Fig. 3 is a cross-sectional view of a specific embodiment of the present invention parallel to its front surface illustrating one type of stiffening structure;

Fig. 4 is a cross-sectional side view of a specific embodiment of the invention; and

Fig. 5 is cross-sectional side view of another specific embodiment of the invention; and

Fig. 6 is cross-sectional side view of still another embodiment of the present invention.

DESCRIPTION OF SPECIFIC EMBODIMENTS

Fig. 1 is a front view of a specific embodiment of a chuck 10 designed according to the present invention. A substrate 12 is shown mounted on the front surface of chuck 10. As can be seen, chuck 10 is substantially thicker than substrate 12 so that substrate 12 will conform to the flatness of the front surface of chuck 10. Three alignment pins 14 provide nominal alignment of substrate 12 to the lithography tool employing chuck 10. The front surface of chuck 10 includes a pattern of holes (not shown) which provide vacuum suction which in turn provides adherence between substrate 12 and chuck 10. The vacuum suction is of sufficient force to cause the substrate to conform to the chuck surface within a tolerance defined by the depth of focus of the optical system. In specific embodiments of the invention, the chuck is larger in its surface dimensions than the substrates with which it is used to ensure that the entire surface of each substrate is in

contact with the chuck. This, in turn, ensures control of the entire substrate.

Fig. 2 is a rear view of chuck 10 of Fig. 1. An array of heat pumps 16 are arranged on the rear surface of chuck 10 in a uniform pattern. Heat pumps 16, which are shown without any heat sinking structures, are adhered to the rear surface of chuck 10 with good thermal contact. In a specific embodiment, heat pumps 16 comprise Peltier thermoelectric heat pumps. As shown in Fig. 2, many relatively small heat pumps are employed to manipulate the temperature of the chuck because, in general, heat pumps 16 and chuck 10 are likely to be made of a different materials having different thermal expansion coefficients. If one large heat pump were used, the differential expansion between the heat pump and the chuck would warp the chuck and therefore the substrate and its image.

Fig. 3 is a cross-sectional view of chuck 10 parallel to its front surface. This view shows substantial side walls 18 providing support for the structure of the chuck. Such side walls are required for most embodiments of the invention employing vacuum suction on the front surface. Also shown in Fig. 3 is an inner stiffening structure 20 comprising a hexagonal “honey comb” pattern of structural webs. As can be seen, stiffening structure 20 forms a plurality of prismatic cells each having a hexagonal cross-section. The longitudinal axes of the cells are substantially perpendicular to the front and rear surfaces of the chuck. It will be understood that there are many other configurations which may be employed to perform the function of stiffening structure 20. For example, periodic structures having a variety of polygonal cross-sections may be substituted for the structure shown.

Stiffening structure 20 provides the chuck with superior specific stiffness and low heat capacity. Stiffening structure 20 also provides a thermal heat path from the rear surface of the chuck which is populated with heat pumps 16 (Fig. 2) to the front surface where the substrate is mounted. In embodiments of the invention where the interior of the

chuck is evacuated (e.g., for vacuum suction) the walls of stiffening structure 20 have apertures which allow pressure to equalize throughout the interior of the chuck thereby preventing distortion of the chuck which might otherwise result from differential pressures in its interior.

Fig. 4 is a cross-sectional side view of a chuck assembly 30 according to a specific embodiment of the invention. A substrate 12 is secured to the front surface 32 of chuck 10. Heat pumps 16 are secured to the rear surface 34. Front and rear surfaces 32 and 34 and stiffening structure 20 form a substantially symmetric assembly. Apertures 36 in the walls of stiffening structure 20 allow pressure equalization inside chuck 10 as described above. Heat sink fins 38 are secured to each heat pump 16. Air flow is directed through the fin array to dissipate the waste heat.

Fig. 5 is a cross-sectional side view of a chuck assembly 40 according to another embodiment of the invention. The embodiment of Fig. 5 is similar to that of Fig. 4 except that in place of heat sink fans, a large isothermal body 42 is secured to heat pumps 16 which provides a low resistance thermal conduction path for waste heat to a nearly ideal heat sink.

Fig. 6 is a cross-sectional side view of a chuck assembly 50 according to still another embodiment of the invention. The embodiment of Fig. 6 utilizes the stiffness and flatness of isothermal mass 42 as a base structure or platen. The chuck therefore does not require the stiffening structure architecture of Figs. 4 and 5. Rather, in this embodiment, substrate 12 is secured to a single piece chuck plate 52 with vacuum suction. Chuck plate 52, heat pumps 16, and isothermal platen 42 are all be mutually adhered together to form a good thermal bond. Heat pumps 16 may be permanently adhered to either chuck plate 52 or isothermal base 42, either separately or as, for example, a Peltier assembly. In any case, the heat pumps are the same thickness to avoid distortion of chuck plate 52. In a specific embodiment, the array of heat pumps 16 are potted together into an assembly and lapped flat.

According to another embodiment, chuck plate 52, heat pumps 16, and isothermal base 42 are coupled together using vacuum suction. The advantage of such an impermanent bond is that stress due to the differential expansion of these chuck assembly elements may be relieved at will. A seal 54 surrounds the perimeter of the array of heat pumps 16 to contain the vacuum, holding all the chuck assembly elements together in good thermal contact, and keeping them flat against isothermal base 42.

To properly function as a substrate chuck, the chuck of the present invention must be stiff and flat, and have means for securing the substrate to the chuck, such as, for example, with vacuum suction as is common in the industry. The chuck may be made from a material with nearly the same thermal expansion coefficient as the substrate material thereby minimizing the chances of inducing stress in the substrate while manipulating the temperature of the chuck. Alternatively, the chuck may be made from a material with a zero thermal expansion coefficient thereby minimizing induced stress that may result in warpage of the chuck while manipulating its temperature.

Low heat capacity and high thermal conductivity of the chuck are also very important. Low heat capacity is important to reducing the amount of energy required to change the temperature of the chuck by a given amount. Low heat capacity is achieved by choosing a material with a low specific heat, and by constructing the chuck with a minimum mass while maintaining the necessary stiffness. One way in which this can be accomplished is by designing the chuck with a hollow core with a stiffening structure and solid outer skins as described with reference to Figs. 4 and 5.

High thermal conductivity is important to maintaining a uniform temperature distribution on the surface of the chuck. A non-uniform temperature distribution over a substrate causes non-uniform magnification and mechanical stress in the substrate. Similarly, undesired temperature gradients in the chuck may cause warpage of the chuck itself which would, in turn, induce magnification and focus errors.

Temperature gradients can also result in localized distortions which can cause localized phenomena such as focus shifts, differential magnification, displacements and rotations which would appear as localized and inconsistent overlay errors. High thermal conductivity of the chuck material also allows both the chuck and the substrate to settle to a uniform temperature quickly.

The thermal chuck of the present invention may also be employed to control the dimensional scale of a substrate in an anisotropic way. For example, if a substrate demonstrates one scaling error in one dimension (e.g., length) and a different scaling error in another dimension (e.g., width), the thermal chuck of the present invention may be used to compensate for these different scaling errors simultaneously by creating one thermal gradient across its length and another across its width. This may be accomplished, for example, using the array of heat pumps 16 shown in Figs. 2 and 4-6. By individually controlling these heat pumps, individual regions within the temperature distribution of the front surface of the chuck may be manipulated, thus allowing many different temperature distributions to be generated. The greater the number of heat pumps and/or the thinner the front surface, the more smoothly the temperature distribution may be controlled.

The present invention may also be employed with other techniques to achieve anisotropic scaling. For example, according to one technique, the thermal chuck is first controlled to provide isotropic manipulation of the substrate thereby compensating for the average scaling error over the substrate. Then, simultaneous with the scan, the relative position of the reticle is smoothly and continuously adjusted with respect to the substrate in the same direction as the scan using an alignment mechanism. According to a more specific embodiment, the thermal chuck is employed to compensate for the average (isotropic) error and some slowly varying anisotropic errors. The smooth and continuous relative motion of the reticle with respect to the substrate is then used to perform fine adjustments which compensate for localized anisotropic errors in the scan axis.

In embodiments where the chuck is constructed of a material having a non-zero thermal expansion coefficient, kinematic support of the chuck is necessary because the chuck changes size relative to is support structure. An over-constrained support structure induces stress in the chuck as its temperature changes resulting in undesirable warping. In embodiments where the chuck is constructed of a material having a zero thermal expansion coefficient, the chuck may be mounted rigidly to a stable structure.

The temperature control system of the invention must be capable of both heating and cooling the chuck and substrate to allow for either polarity of magnification. It must also be capable of heating and cooling quickly. Heating quickly and with uniformity is relatively easy with ohmic heaters. However, cooling is much more difficult. Circulation of chilled water is an option, but this technique is relatively slow due to the thermal mass of the water and the circulation time. Peltier thermoelectric heat pump devices are an excellent option which provide temperature agility, high heat rates, and good uniformity where many devices are spaced evenly over the surface of the chuck. With Peltier devices the waste heat from the heat transfer operation is removed from the back side of the Peltier devices. For removal of this waste heat, water circulation may be employed since high heat capacity is desirable and response time is not critical.

Because they are likely to have a different thermal expansion coefficient than the chuck, the individual Peltier devices should be relatively small in area so that the stresses in the chuck which are induced as it changes temperature are minimized. Differential stress can be minimized further by securing the Peltier devices to the chuck with a high thermal conductivity adhesive which also has a relatively low modulus of elasticity.

An alternative method for removing waste heat from the Peltier devices is the use of forced air over or through heat sink fins on the backs of the Peltier devices. Another method for removing waste heat from the Peltier devices may be used only with embodiments where the chuck is constructed of a

zero thermal expansion coefficient material, or where a stress relieving technique is employed which removes induced stresses from the chuck assembly and/or substrate. This technique involves sandwiching the Peltier devices between the chuck and a flat, massive, constant temperature structure having a high thermal conductivity.

In specific embodiments, temperature sensors such as, for example, thermocouples or thermistors, are attached to the chuck to monitor and facilitate the control of its temperature distribution. Such sensors are particularly useful for embodiments of the invention which exercise anisotropic control of the chuck's temperature distribution.

A measure of the suitability of a given material for use with the present invention, i.e., a "goodness factor", can be determined with reference to various of the characteristics discussed above. Such a goodness factor, G, is given by the relationship:

$$G = \frac{(\text{specific stiffness}) \times (\text{thermal conductivity})}{(\text{specific heat})}. \qquad (1)$$

A comparison of many common engineering materials has shown graphite and beryllium oxide (BeO) as particularly "good" materials from which to construct the chuck. The outer skins (i.e., front and rear surfaces) of the chuck are preferably at least as thick as the substrate to facilitate the effective distribution of heat, as well as to provide sufficient stiffness relative to the stiffness of the substrate. According to specific embodiments, the inner stiffening structure is constructed of the same material as the outer skins to maintain dimensional stability. However, in some embodiments, the stiffening structure may also be plated with a material having a high thermal conductivity and a low elastic modulus such as, for example, copper (Cu) or aluminum (Al), to increase thermal conductivity between the front and rear surfaces of the chuck. When employing such a stiffening structure it is important to maintain the symmetry of the chuck assembly structure.

According to a specific embodiment of the invention, a substrate is loaded onto the chuck (of Figs. 1-3) and a soft vacuum is applied to secure the substrate sufficiently to establish good thermal contact with the chuck surface, but also allow for differential expansion between the substrate and the chuck. The scale of the image on the substrate is measured to determine the scale adjustment required to match the scale of the photomask image. More specifically, the rotational misalignment and the isotropic magnification error are determined as follows. Initially, a simple alignment between the substrate and the reticle is achieved by measuring the alignment errors $(\Delta x_1, \Delta y_1)$ between a point (x_1, y_1) on the substrate and its corresponding point on the reticle, and then adjusting the x,y position of either the substrate or the reticle to reduce the error to zero. Once this simple alignment is achieved, alignment data $(\Delta x_2, \Delta y_2)$ is acquired for a second point (x_2, y_2) on the substrate and its corresponding point on the reticle. The rotational misalignment between the reticle and the substrate is given by

$$[\Delta x_2/(y_2-y_1) + \Delta y_2/(x_2-x_1)]/2 \qquad (2)$$

and the isotropic or average magnification error is given by

$$[\Delta y_2/(y_2-y_1) + \Delta x_2/(x_2-x_1)]/2 \qquad (3)$$

According to another embodiment, a fairly rigorous alignment between the substrate and the reticle is conducted (especially where the expansion behavior of the substrate is not known) by measuring the alignment errors $(\Delta x_i, \Delta y_i)$ between a point on the substrate and its corresponding point on the reticle, and then repeating the process for at least two more points on the substrate. Once the data have been collected, they may be analyzed using the following expressions:

$$\delta x = \alpha x + (\Delta M/M)x_0 - \theta y_0 + \epsilon \qquad (4)$$

$$\delta y = \alpha y + (\Delta M/M)y_0 - \theta x_0 - \epsilon \qquad (5)$$

where the constants αx and αy correspond to an origin shift. The terms which are linear in field placement are due to magnification errors ($\Delta M/M$) and reticle rotation errors. Once the normal equations are solved, the temperature change needed to compensate for scaling errors may be applied. Appropriate rotational adjustment may also be applied to compensate for rotation errors. Repeating the alignment process may be required to confirm or refine the result. For subsequent repetitions of the alignment process, fewer alignment points may be employed to reduce overall alignment time. The number of alignment points may also be reduced for subsequent substrates as the behavior of the substrate scaling becomes known. However, the number of alignment points on any given substrate may not be reduced below two if proper rotational alignment is to be achieved.

For cases of anisotropic expansion, more than two alignment points are required to determine the scale error as a function of position on the substrate. For constant but different scales in two dimensions, three non-collinear alignment points are required to determine the scale in the two dimensions in addition to overlay in two translational and one rotational axes. If there are linear scale gradients in two dimensions, five alignments points are required. When higher order scale errors occur, some pattern or degree of predictability may also occur. If the coefficients of the higher order terms can be correlated to the first order scale, a determination of the first order scale using only two alignment points may suffice.

The temperature of the substrate and chuck is also measured. The temperature of the substrate and chuck which would provide the necessary expansion or contraction of the substrate to minimize the scale error is then calculated. The temperature of the substrate and chuck is then servoed to the desired value by heating or cooling the chuck mass as required. After thermal equilibrium of the substrate and chuck assembly is achieved, a stronger vacuum is applied to more firmly secure the substrate to the chuck for the photolithographic process.

For the embodiment of the invention which employs an isothermal platen without permanently adhered components (e.g., the chuck assembly described above with reference to Fig. 6), the vacuum that holds the chuck and the heat pumps to the isothermal platen may be relaxed momentarily after thermal equilibrium is achieved to allow any stress resulting from differential expansion to be released.

To further augment the reduction of overlay errors using the thermal chuck of the present invention, instead of aligning the photomask image only once to the entire substrate image, a specific embodiment of the invention aligns each individual panel (or potentially many isolated areas) on a substrate to the corresponding photomask area before exposure of that particular area, repeating the process for each area on the substrate. This technique is particularly useful where there are multiple panels (e.g., product images) on a single substrate.

Various embodiments of the invention may be useful in, for example, the manufacture of flat panel displays (FPDs). Thermal, thin-film and compaction effects in FPD processes have been or can be characterized. To a significant extent, therefore, the effective magnification change of the substrate for each step of such a process may be predicted. Using this information, the present invention may be operated in a so-called static mode in which a single constant chuck temperature is employed for each process step, i.e., the scale of the substrate may be manipulated for each process step to compensate for the magnification change corresponding to the particular process step. In a more specific embodiment, differently scaled reticles could be produced for selected process steps thereby reducing the required dynamic range of the thermal chuck. That is, part of the compensation for overlay mismatch may be achieved by the use of differently scaled reticles and part may be achieved using the properties of the thermal chuck as described above.

It should also be noted that, because a substrate chuck represents a relatively costly system element when compared to the cost of a single substrate, it is important

that the front surface of a substrate chuck be harder than the substrates it is designed to handle so that the substrates do not abrade the surface of the chuck.

The above description is illustrative and not restrictive. Many variations of the invention will become apparent to those skilled in the art upon review of this disclosure. For example, different materials of construction may be used if chosen carefully. The invention can be mounted in various orientations, and with a variety of mounting techniques. It can incorporate various sensors to facilitate operation. Holes or other means may be added to the chuck surface or structure to facilitate substrate exchange. Different operating sequences can be used to tailor operation to a particular application. To decrease the time required for a substrate to get to a new equilibrium temperature on the thermal chuck, the substrates in a cassette could be preheated with heated air to a temperature near the average temperature of the thermal chuck. This invention may also be incorporated into many different types of equipment. The scope of the invention should therefore be determined not just with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents.

WHAT IS CLAIMED IS:

1. A chuck assembly for holding a substrate, comprising:

a front surface to which the substrate adheres, the front surface having means for securing the substrate to the front surface, the front surface being characterized by a temperature distribution; and

coupled to the front surface, a plurality of temperature control devices for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface.

2. The chuck assembly of claim 1 wherein the means for securing the substrate to the front surface comprise a plurality of suction apertures in the front surface.

3. The chuck assembly of claim 1 wherein the means for securing the substrate to the front surface are operable to provide a plurality of levels of adherence between the substrate and the front surface.

4. The chuck assembly of claim 1 wherein the plurality of temperature control devices is operable to create an anisotropic temperature distribution across the front surface of the chuck assembly.

5. The chuck assembly of claim 1 further comprising a rear surface coupled to and opposite the front surface, the plurality of temperature control devices being spaced uniformly on the rear surface.

6. The chuck assembly of claim 1 wherein each of the plurality of temperature control devices comprises a Peltier heat pump.

7. The chuck assembly of claim 1 wherein each of the plurality of temperature control devices is individually controlled.

8. The chuck assembly of claim 1 wherein each of the plurality of temperature control devices has an individual heat sink coupled thereto.

9. The chuck assembly of claim 1 further comprising a rear surface coupled to the front surface via a stiffening structure by which heat may be conducted from the rear surface to the front surface.

10. The chuck assembly of claim 9 wherein the stiffening structure forms a plurality of prismatic cells each having a polygonal cross-section, a longitudinal axis, and walls, the longitudinal axes of the prismatic cells being substantially perpendicular to the front and rear surfaces of the chuck assembly.

11. The chuck assembly of claim 10 wherein each of the prismatic cells has apertures formed in the walls thereof to prevent differential pressures from forming within the chuck assembly.

12. The chuck assembly of claim 1 wherein the front surface of the chuck assembly comprises a material characterized by a zero thermal expansion coefficient.

13. The chuck assembly of claim 1 wherein the front surface of the chuck assembly and the substrate are characterized by thermal expansion coefficients which are substantially the same.

14. A chuck assembly for holding a substrate for photolithographic processing, comprising:

a front surface to which the substrate adheres, the front surface having a plurality of suction apertures for

securing the substrate to the front surface, the front surface being characterized by a temperature distribution; and

a rear surface coupled to and opposite the front surface, the rear surface having a plurality of temperature control devices spaced uniformly thereon for manipulating the temperature distribution of the front surface, thereby allowing controlled expansion and contraction of the substrate adhered to the front surface.

15. The chuck assembly of claim 14 further comprising a base coupled to the plurality of temperature control devices opposite the rear surface, the base, the plurality of temperature control devices, and the rear surface being held together using vacuum suction.

16. The chuck assembly of claim 14 wherein the plurality of temperature control devices is operable to create an anisotropic temperature distribution across the front surface of the chuck assembly.

17. A method for providing control of the scale of a substrate comprising the steps of:

adhering the substrate to a front surface of a chuck, the front surface being characterized by a temperature distribution; and

controlling a plurality of temperature control devices coupled to the front surface of the chuck, thereby manipulating the temperature distribution of the front surface of the chuck, thereby adjusting the scale of the substrate.

18. The method of claim 17 wherein the adhering step comprises providing a plurality of levels of adherence, differing levels of adherence being employed to compensate for scale changes resulting from the manipulating step.

19. The method of claim 17 wherein the adhering step comprises providing a first level of adherence between the substrate and the front surface of the chuck, the method

further comprising the step of providing a second level of adherence between the substrate and the front surface of the chuck to relieve stress on the substrate resulting from the manipulating step, the second level of adherence being less than the first level of adherence.

20. The method of claim 17 wherein the adhering step comprises providing a first level of adherence between the substrate and the front surface of the chuck, the method further comprising the step of providing a second level of adherence between the substrate and the front surface of the chuck to more securely couple the substrate to the front surface of the chuck, the second level of adherence being greater than the first level of adherence.

21. The method of claim 17 wherein the manipulating step comprises uniformly manipulating the temperature distribution of the front surface of the chuck to effect isotropic control of the scale of the substrate.

22. The method of claim 17 wherein the manipulating step comprises selectively manipulating the temperature distribution of the front surface of the chuck to effect anisotropic control of the scale of the substrate.

23. The method of claim 17 wherein the manipulating step comprises uniformly increasing the temperature of the front surface thereby resulting in controlled expansion of the substrate.

24. The method of claim 17 wherein the manipulating step comprises uniformly decreasing the temperature of the front surface thereby resulting in controlled contraction of the substrate.

25. The method of claim 17 wherein the manipulating step comprises adjusting the scale of the substrate until a first image on the substrate has reached a first scale, the

first scale being determined with reference to a second image on an associated reticle.

26. The method of claim 25 wherein the first image comprises a plurality of portions, the step of adjusting the scale of the substrate being performed for each portion of the first image.

27. The method of claim 17 wherein the manipulating step adjusts the scale of the substrate with reference to a reticle pattern, the method further comprising the step of determining an alignment error by comparing a plurality of alignment points on the substrate to corresponding locations on the reticle pattern, the manipulating step adjusting the scale of the substrate to compensate for the alignment error.

28. The method of claim 27 wherein the substrate is characterized by anisotropic expansion and the plurality of alignment points comprises at least three alignment points which are not collinear.

29. The method of claim 28 wherein the anisotropic expansion is characterized by linear gradients in two dimensions and the at least three alignment points comprise at least five alignment points.

30. The method of claim 17 wherein the chuck is characterized by an average temperature and the steps of adhering and manipulating are performed for a plurality of substrates, the plurality of substrates being stored in a cassette before the adhering and manipulating steps, the method further comprising the step of preheating the plurality of substrates stored in the cassette to the average temperature of the chuck.

31. A method for providing control of the scale of a substrate in a photolithographic process, the method comprising the steps of:

providing a plurality of levels of adherence between the substrate and a front surface of a chuck, the front surface being characterized by a temperature distribution; and

manipulating the temperature distribution of the front surface of the chuck, thereby adjusting the scale of the substrate to a first scale, the first scale being determined with reference to a second image on an associated reticle;

wherein differing levels of adherence are employed to compensate for scale changes resulting from the manipulating step.

32. A method for providing control of the scale of a substrate in a photolithographic process, the photolithographic process having a plurality of process steps, each process step being characterized by a magnification change of the substrate, the method comprising the steps of:

adhering the substrate to a front surface of a chuck, the front surface being characterized by a temperature distribution; and

manipulating the temperature distribution of the front surface of the chuck for each process step, thereby adjusting the scale of the substrate to compensate for the corresponding magnification change.

33. The method of claim 32 wherein the front surface of the chuck is characterized by a dynamic range, the method further comprising the step of providing differently scaled reticles for at least one process step thereby partially compensating for the corresponding magnification change.

34. A method for compensating for scaling errors in a photolithographic process wherein a reticle has relative position with respect to a substrate, the method comprising the steps of:

adhering the substrate to a front surface of a chuck, the front surface being characterized by a temperature distribution;

manipulating the temperature distribution of the front surface of the chuck, thereby adjusting the scale of the substrate;

performing a photolithographic scan of the substrate; and

simultaneous with the photolithographic scan, adjusting the relative position of the reticle with respect to the substrate in a substantially continuous manner thereby compensating for localized anisotropic scaling errors.

35. The method of claim 34 wherein the temperature distribution of the front surface of the chuck is manipulated to compensate for isotropic scaling errors.

36. The method of claim 35 wherein the temperature distribution of the front surface of the chuck is also manipulated to compensate for slowly varying anisotropic errors.

37. A method for compensating for scaling errors in a photolithographic process wherein a reticle has relative position with respect to a substrate, the method comprising the steps of:

performing a photolithographic scan of the substrate; and

simultaneous with the photolithographic scan, adjusting the relative position of the reticle with respect to the substrate in a substantially continuous manner thereby compensating for localized anisotropic scaling errors.

38. A chuck assembly for holding a substrate, comprising:

a front surface to which the substrate adheres, the front surface having means for securing the substrate to the front surface, the front surface being characterized by a temperature distribution; and

coupled to the front surface, means for manipulating the temperature distribution of the front surface, thereby

allowing controlled expansion and contraction of the substrate adhered to the front surface, the manipulating means being operable to independently control a plurality of regions within the temperature distribution.

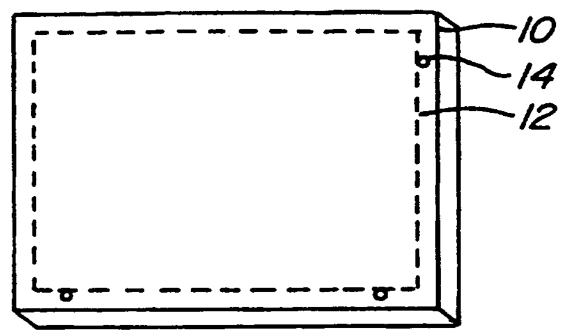

FIG. 1.

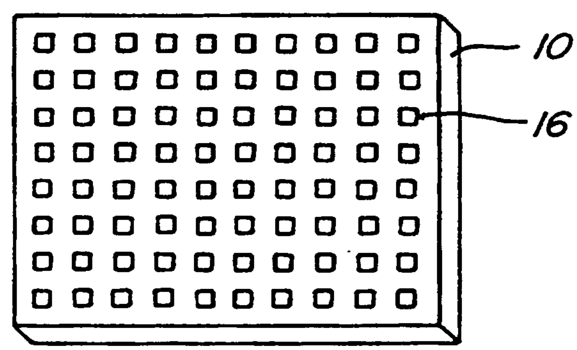

FIG. 2.

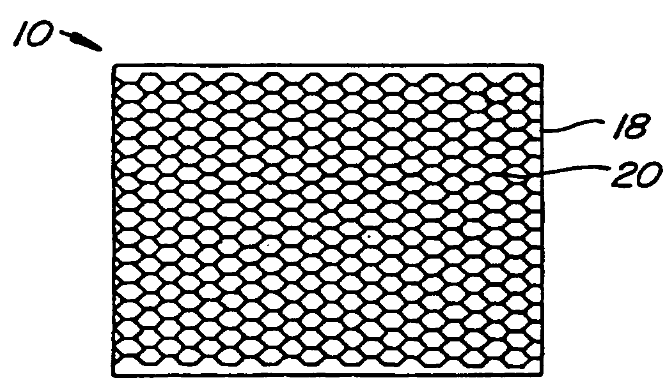

FIG. 3.

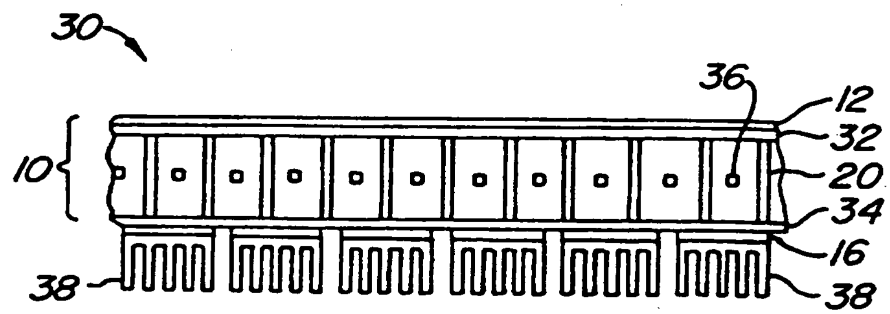

FIG. 4.

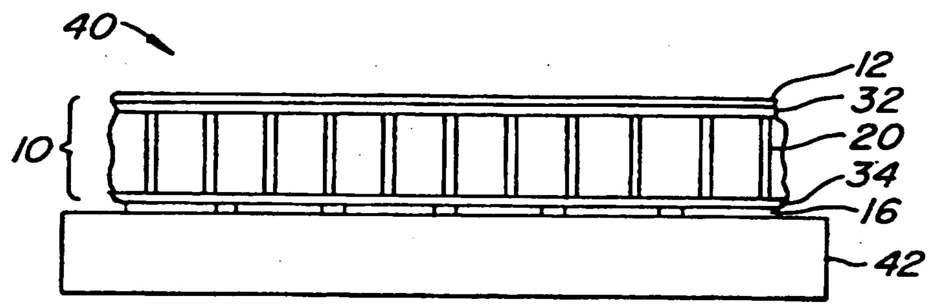

FIG. 5.

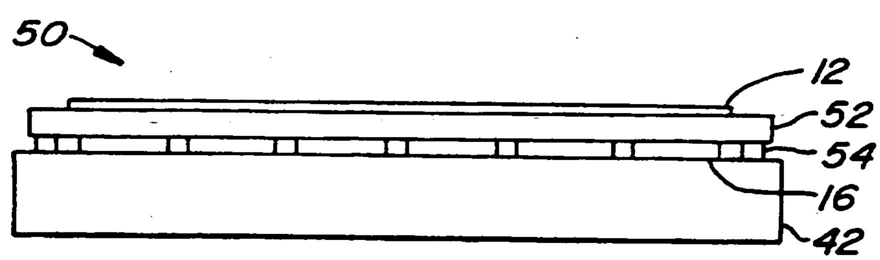

FIG. 6.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/16272

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G03B 27/34; H01L 21/30
US CL : 355/30, 72, 73; 219/385
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 355/30, 53, 55, 72, 73, 91; 219/243, 385, 405, 411, 526; 118/50.1, 728

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, JAPIO, WPIDS
search terms: wafer, semiconductor, substrate, chuck, temperature, vacuum

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,134,436A (Fujioka) 28 JULY 1992 col. 4, lines 1-6, 48-64 col. 6, lines 49-68 Figs. 2B, 6	1, 4-8, 14, 16, 17, 21-24, 38
Y	US 4,564,284A (Tsutsui) 14 JANUARY 1986 col. 3, lines 6-46, 68-69 col. 4, lines 1-20	12, 13
Y	US 5,155,652A (Logan et al.) 13 OCTOBER 1992 Fig. 1 col. 3, lines 54-68 col. 4, lines 1-13	9-11
A	US 4,503,335A (Takahashi) 05 MARCH 1985	1-16, 38

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 JANUARY 1997	20 FEB 1997

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	DAVID A. LANE
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/16272

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,270,771A (Sato) 14 DECEMBER 1993 Figs. 2-4 col. 2, lines 40-50	27-28
Y	US 5,563,683A (Kamiya) 08 OCTOBER 1996 col. 2, lines 39-65 Figs. 4, 5A-B	2-3, 15

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